International Journal of Smart Vehicles and Smart Transportation
Volume 4 • Issue 1 • January-June 2021

Operation of VANET Communications:
The Convergence of UAV System With LTE/4G and WAVE Technologies

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ABSTRACT

This work proposed an integrated novel architecture of UAV System, LTE/4G, and WAVE technologies with its forwarding schemes in highway scenario to enhance the VANET communications and achieve the requirements of its basic applications, particularly safety and traffic. Algorithms for UAV sensing, tagging (based on the proposed safety and traffic info model), and broadcasting operations, and forwarding of safety or traffic info to respective infrastructures, and then smart ground vehicles are designed, particularly to minimize intermittent connectivity and bandwidth usage as well as to satisfy the requirements of VANET applications. The authors have evaluated the performance of the integrated novel architecture with its forwarding schemes/algorithms through integrated and simulated VANETs and wireless access technologies (LTE/4G and UAV system) environment.

KEYWORDS

Integrated Wireless Technologies in VANETs, LTE/4G, UAV, VANET, WAVE

1. INTRODUCTION

Driven by high demand of road safety and navigation accuracy, vehicle communications are becoming increasingly popular nowadays. After years of development of wireless communication and mobile ad hoc network, the concept of VANET (Vehicular Ad Hoc Network) has come forward and built foundation for unlimited forms of vehicle-to-vehicle applications. New standards for vehicular communication such as DSRC (Dedicated Short-Range Communications (Qing et al., 2004)) and more recent IEEE 802.11p (Wireless Access in Vehicular Environment, WAVE (Daniel & Luca, 2008)) are emerging, which enhances the effectiveness and feasibility of vehicular communications.

With the innovation and rapid development in personal digital gadgets, especially smart phones and wearable devices, people have naturally increased their demand in the interconnectivity of things around them. Vehicles are now an indispensable part in our life. By embedding new technology, manufacturers are broadening our view of vehicles from a source of transportation to an integrated center of information and recreation. People have been exploring new possibilities in vehicular applications such as the vehicle-to-vehicle communication protocol for cooperative collision warning proposed in (Xue et al., 2004) and the smart parking scheme for large parking lots based on VANET proposed in (Rongxing et al., 2009). However, most of these VANET applications need extra infrastructure, which makes them hard to deploy.

DOI: 10.4018/IJSVST.2021010103

Vehicular communication is usually developed as a part of ITS and governing by the ISO/ETSI reference communications stack. Generally, the communication mode of VANET classified V2V and V2I respectively (Issac & Latiff, 2014). V2V has uses the OBU to communicate with one another, which enables distributed pattern of communication among vehicles with decentralized coordination. While V2I has vehicles communicate to RSU so as to enhance communication range by sending and receiving information from a vehicle to another vehicle. However, these two types of VANET communications have their own constraints within various scenarios. For instance, V2V communication in highway scenario, to broadcast time-critical information like traffic accident warnings, it has completely depended on the sparseness and swiftness of vehicles. Thus, it will be difficult to achieve the goal of safety applications due to intermittent connectivity. Additionally, each vehicle periodically broadcasts a beacon or hello message to each other that used to exchange their current states and surrounding info. Due to this circumstance, they have consumed a high bandwidth from limited VANETs spectrum (75 MHz). Whereas, V2I communication in urban and highway scenarios, the effectiveness of the communication between smart ground vehicles and roadside infrastructures mostly depends on the capability of roadside infrastructures. Thus, it will be expected from VANETs technologists and scholars to bring out pretty solutions for these types of constraints incorporate with the existing ones.

In this paper, we have evaluated the performance of the converged novel architecture with its forwarding schemes/algorithms in highway scenario (Estifanos, 2018) through integrated and simulated VANETs and wireless access technologies (LTE/4G and UAV System) environment. The contributions of the paper are mentioned as follows. These are:

- The paper implemented the proposed novel architecture (Estifanos, 2018).
- It proved that the proposed novel architecture (Estifanos, 2018) is better than the existing ones (Issac & Latiff, 2014), (Vehicular Communication Systems, 2020), (Fan & Yu, 2007), (Saheb et al., 2006) interms of packet delivery, mean delay and throughput on highway scenario.
- It proved that different wireless technologies like LTE/4G and WAVE can be simulated on the integrated simulation environment.
- And based on its evaluation results, it recommend a lot of and basic open issues as listed on conclusion section.

2. LITERATURE REVIEW

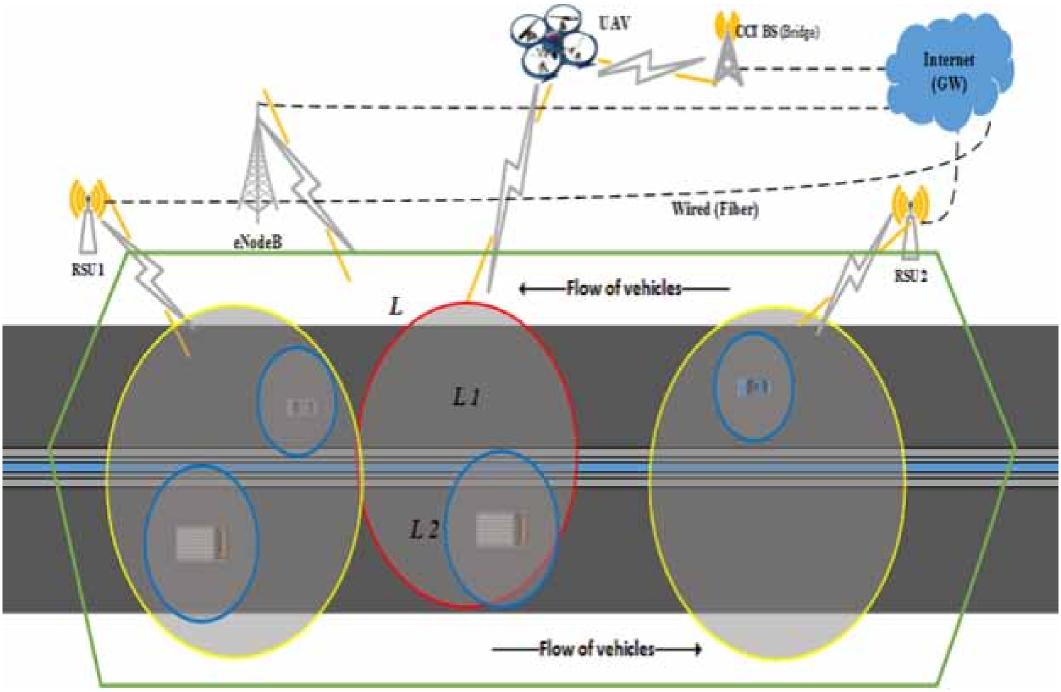
Our performance evaluation has done based on the work of performance optimizing of VANET communication by integrating the UAV system with LTE/4G and WAVE technologies (Estifanos, 2018). Thus, as a literature review, we have discussed the work of architectures, the proposed UAV's periodically sensing, tagging and broadcasting of vehicle in formation scheme and the proposed forwarding model of the tagged information to infrastructures.

2.1 Architecture of the Proposed Solution

In (Estifanos, 2018) the basic architecture of the proposed solution has been designed based on the integrated UAV system with LTE/4G and WAVE technologies. The paper presented a detail description about how a UAV periodically sense, tag and broadcast of vehicles information and the proposed forwarding model of the tagged information to infrastructures.

Figure 1 depicts the general low-level architecture of the proposed solution in highway scenario. In this low level architecture, there are three fundamental wireless network infrastructures are designed (UAV, LTE/4G and RSUs) with their respective positions and the author assumed that the transmission range of each infrastructure and smart ground vehicle has considered as an ideal cell. He assumed that the single small UAV system is a full autonomous Quadrotor Drone (4 Rotor wing) type that does not

Figure 1. General Low-Level Architecture of the Proposed Solution (Estifanos, 2018)



require any direct human intervention for flying (uplink communication) and it capable to hover on a specific area for a while. In (Estifanos, 2018) the paper doesn't presented the drone's battery backup issue. However, we will recommend to use sunlight energy during real implementation.

The system has deployed on the middle highway segment with around 10m altitude (height) of UAV flight from the ground and its transmission range covered nearby 150-200 meter, and completely confined by the transmission range of LTE/4G. The drone has a hovering motion over the area of sensing operation and proceed a different types of communications such as with smart ground vehicles and LTE/4G via IEEE 802.11b/g interface with the help of its CCT BS/GCS.

In the proposed architecture, there is a downlink communication that used to UAV for broadcasting the sensed information (tagged packet) within the transmission range. In order to this, the drone on-board vehicles and GCS will receive the broadcasted packet via LOS or direct radio link of IEEE 802.11b communication. Besides, the GCS that present in the proposed model has also used as a gateway to make a communication between UAV and LTE/RSUs.

Whereas the LTE/4G network has designed on the highway segment as one of the wireless access network infrastructures. The paper supposed that the eNB cell covered about 1km which means it can completely cover the transmission range of the other deployed infrastructures as shown in Fig 1.1. The network can communicate with the UAV system through its core network (EPC server). Likewise, the LTE/4G network can make a direct communication with E-UTRAN on-board mounted vehicles (driver's LTE equipped cell phone) when those vehicles being in the eNodeB cell.

Two RSUs (DSRC/WAVE) have also designed as a left and right sides of UAV system respectively. The author assumed that each RSU has about 250-300m coverage area and absolutely confined by LTE/4G transmission range as like as UAV system. They are also connected with UAV system via Internet or their own gateways and can proceed a communication. Moreover, the infrastructures can make direct communications with WAVE-enabled vehicles via IEEE 802.11p wireless interface when those vehicles being in the RSUs coverage area. Furthermore, the paper has considered a few basic

assumptions on the proposed architecture. Such as, a deployment distance between infrastructures, the flow and transmission range of vehicles, and street type.

The work supposed that the deployment distance between RSU 1 (the left one) and UAV, and again between UAV system and RSU 2 (the right one) have about 180 and 300 meter respectively. However, the deployment distance of eNB is not compulsory because it has a high coverage area than others, thus the author assumed that wherever eNB deployed, it has not any significant effect in the proposed architecture. Though, to better clarification of the proposed system, he simply deployed the eNB about 80 meter far away from RSU 1 (the left one).

While the work assumed that the transmission range of vehicles is less than the range of remaining deployed wireless access infrastructures and it varies from vehicle to vehicle as shown in Fig 1. And also the vehicles highly exposed for intermittent connectivity due to a highway scenario and their own dynamic movements. Additionally, the paper considered the street type as a two lanes highway with different flow of directions which means on the upper lane, the flow of vehicles proceeds from right to left whereas on the lower lane, it proceeds from left to right as demonstrated in Fig 1.

Figure 2 depicts the high-level architecture of the proposed solution in highway scenario. In the architecture, there are four core modules. These are Unmanned Aerial Vehicle (UAV), Long Term Evolution (LTE/4G), Road Side Unit (RSU 1/RSU 2) and Smart Ground Vehicle modules. And also there are four proposed forwarding schemas that from UAV (GCS) to LTE/4G, UAV (GCS) to RSU 1/RSU 2, LTE/4G to Smart Ground Vehicles and RSU 1/RSU 2 to Smart Ground Vehicles respectively.

2.1.1 The Proposed UAV's Periodically Sensing, Tagging and Broadcasting of Vehicles Information

In this section, we have stated the work (Estifanos, 2018) that designed a single small UAV's periodically sensing, tagging and broadcasting operations of the current states of drone-mounted vehicles info within UAV coverage area to minimize a bandwidth consumption of vehicles that periodically broadcast their current states to other nearest vehicles and RSUs. The author has designed a pseudo code that helps to UAV's basic operations as stated in Algorithm 1.

Algorithm 1 shows the pseudo code of UAV's sensing, tagging and broadcasting operations of vehicles info in the highway environment.

Algorithm 1. Algorithm for UAV's Sensing, Tagging and Broadcasting Operations of Drone-mounted Vehicles Info (Estifanos, 2018)

```
  Input: Vehicles n
  Process:
1. UAV (Drone) broadcast a beacon message in every 0.5 second
within its own range
2. While (Vehicle (on-board drone) received a beaconed message) Do
3. Drone sense a current position of vehicles // by GPS
4. Drone sense a current speed of vehicles // by Accelerometer
5. Drone sense a current total number and ID of vehicles //  by
counter
6. IF (the current speed of one of vehicles >= 120 km/h) //  from
L1 and/or L2
7.        The Drone tag all of the above sensed information in
Safety Info module // L
8.       Drone broadcast the tagged packet within its own coverage
area
9.   ENDIF
10. ELSE
```

```
IF (the current speed of all vehicles < 120 km/h) // from L1 and/or L2
IF (L1 && L2 exist)
                    The Drone tag L1 and L2 in different Traffic Info Modules
                    Drone broadcast the tagged packets within its own coverage area
              ENDIF
              ELSE
IF (L1 || L2 exist)
                            The Drone tag L1 or L2 in a single Traffic Info Module
                            Drone broadcast the tagged packet within its own coverage area
                      ENDIF
          ENDIF
    ENDWhile
Output: Vehicles Info in highway environment is sensed, tagged and broadcasted in a MAVLink packet
```

2.1.2 The Proposed Forwarding Model of the Tagged Information to Infrastructures

In this section, we have discussed the work (Estifanos, 2018) that proposed a forwarding model of the tagged information to infrastructures.

After accomplished the operations of sensing, tagging and broadcasting information by UAV, the actual forwarding of the sensed information to the respective infrastructures will proceed via UAV's GCS.

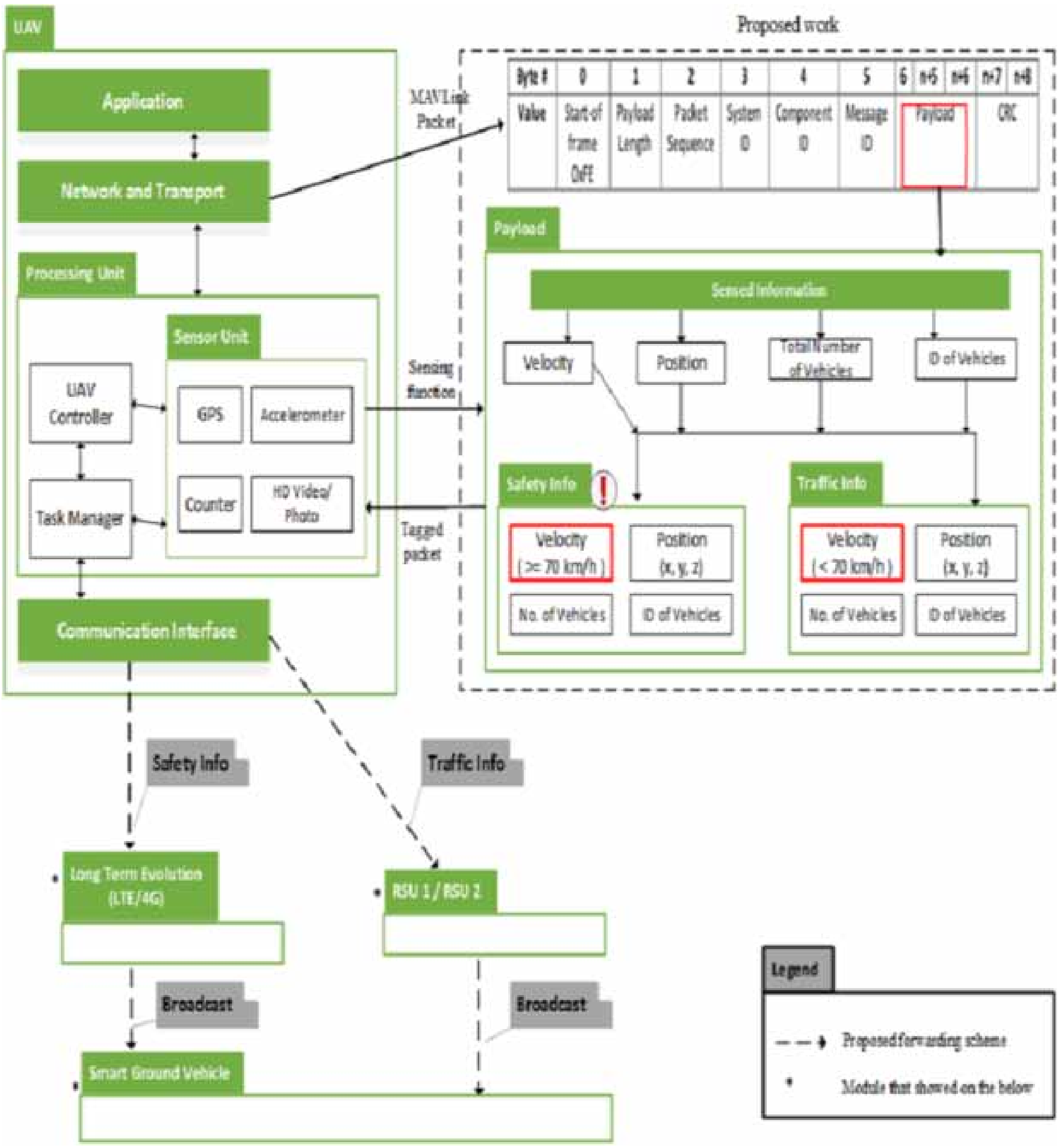
In this phase, the author has used one of the models of tagged information which capable to optimize the forwarding schemas as shown in Figure 4, Algorithm 2 and Algorithm 3.

After UAV broadcasted the tagged information within its own transmission range, the drone-mounted ground vehicles and GCS within UAV's transmission range will receive the broadcasted packet via LOS or direct radio link of IEEE 802.11b communications. Then the GCS will proceed again the inspection process that the received packet as for whether it is safety or traffic information depending on the packet's tagged vehicles speed.

If there is a safety information that a high vehicles speed from the accepted one (120 km/h), the GCS will forward it to the LTE-enabled vehicles through the LTE/4G core network to satisfy the nature of the information/application that required a high data rate and coverage area as shown in Fig 4 and Algorithm 2. During this forwarding process, the tagged packet will be an EPS bearer deliberately by EPC server or LTE/4G core network because the eNB has only process and propagate an EPS bearer packets within its own cell.

Whereas, if there is a traffic information that the speed of all vehicles is less than the accepted one (120 km/h) in **L1** and/or **L2**, the GCS will forward the information to the respective RSUs. In other word, if the GCS will receive **L1** in a single MAVLink packet, then GCS will only forward it to RSU 2 as shown in Fig 4 and Algorithm 3 because **L1** is most mandatory for smart ground vehicles moving from right to left and found within a coverage area of RSU 2. While if the GCS will receive **L2** in a single MAVLink packet, then GCS will only forward it to RSU 1 as shown in Fig 4 and Algorithm 3, because **L2** is most significant for smart ground vehicles those moving from left to right and being within transmission range of RSU 1. Otherwise, if the GCS will receive **L1** and **L2** in different single MAVLink packets, then GCS will forward **L1** to RSU 2 and **L2** to RSU 1 concurrently. Generally, the paper assumed that proposed forwarding schemes of traffic information

Figure 2. General High-Level Architecture of the Proposed Solution (Estifanos, 2018)



to RSUs will minimize the bandwidth usage when the RSUs broadcast the information to WAVE-enabled vehicles within their own coverage areas.

2.1.3 Propagating the Sensed Information to the Target Smart Ground Vehicles

As demonstrated in Figure 4, propagating the forwarded Information to the target smart ground vehicles is designed.

When a GCS forward a safety information to 4G-enabled vehicles via EPC server or LTE/4G core network, the eNodeB will be used to broadcast the information with EPS to the 4G-enabled vehicles within the eNB cell as shown in Fig 4 and Algorithm 2. In order to this, all 4G-enabled vehicles present in eNB cell will receive the safety information. In VANET environment, the safety applications require a high data rate and coverage area because they are delay-sensitive applications.

Figure 3. The Remaining Modules in General High-Level Architecture of the Proposed Solution (Estifanos, 2018)

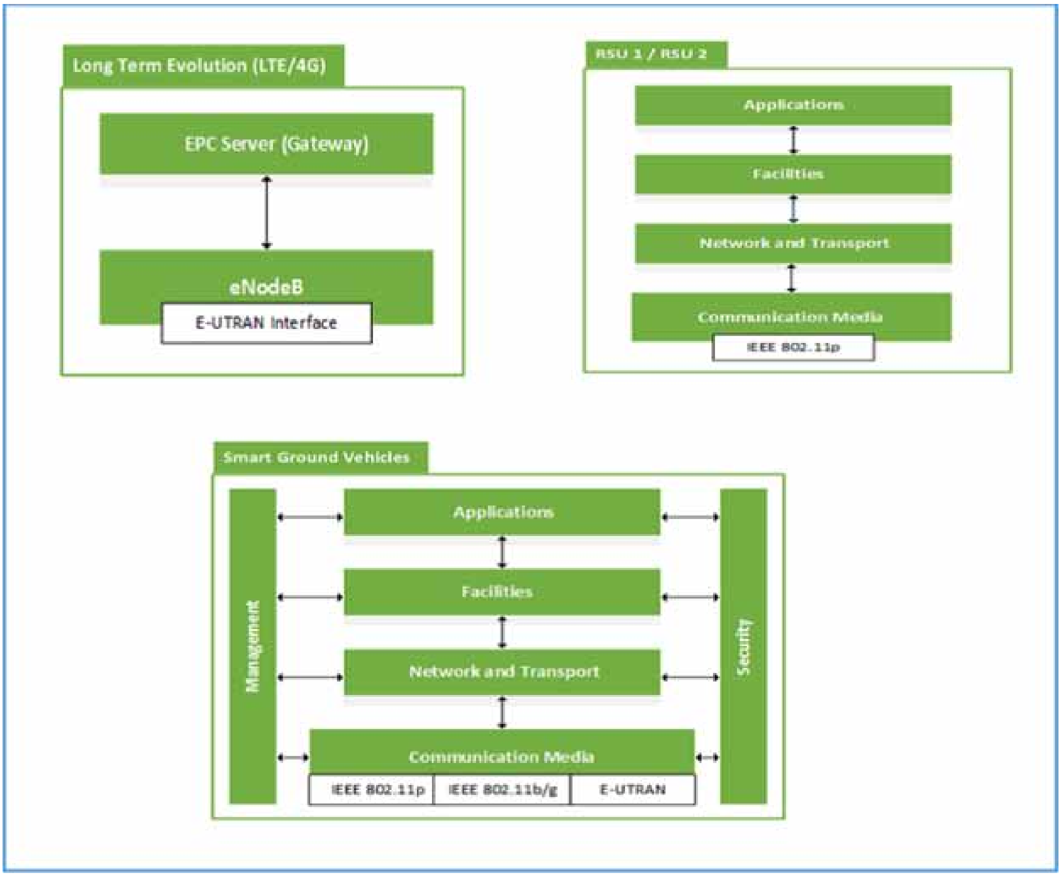
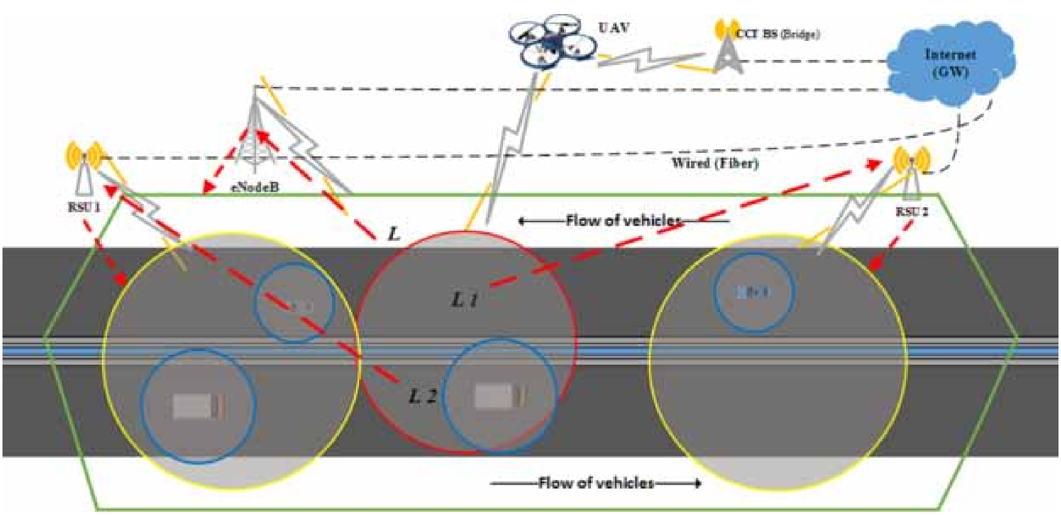


Figure 4. The Proposed Forwarding Schemes of the Sensed Information (Tagged Packets) (Estifanos, 2018)



Whereas, when a GCS forwards a traffic information to RSUs, the RSUs will broadcast the information to the WAVE-enabled vehicles found in the coverage area of RSUs. In other word, when GCS forwarded **L1** to RSU 2, then the RSU 2 will immediately broadcast it to WAVE-enabled vehicles within its own transmission range. While, when GCS forwarded **L2** to RSU 1, the RSU 1 will instantly broadcast it to vehicles within its own coverage area. Otherwise, when GCS simultaneously forwarded **L1** and **L2** to RSU 2 and RSU 1 respectively, then the RSU 2 will broadcast **L1** and RSU 1 will broadcast **L2** to vehicles within their own transmission ranges as shown in Fig 4 and Algorithm 3.

Algorithm 2 shows the pseudo code of the proposed forwarding and propagating schemas of safety information to the target 4G-enabled vehicles.

Algorithm 2. Algorithm for Forwarding and Broadcasting of Safety Info to 4G-enabled Vehicles

```
Input: Vehicles n
Process:
1. While (GCS received the broadcasted tagged packet from UAV) Do
2.          IF (the speed of vehicle >= 120 km/h) // check L by
GCS
3.           GCS forward the tagged packet (L) to all LTE/4G-
enabled vehicles via EPC server and eNB cell
4.        ENDIF
5.  ENDWhile
Output: The safety information is broadcasted to all LTE/4G-
enabled vehicles
```

Algorithm 3 shows the pseudo code of the proposed forwarding and propagating schemas of traffic information to respective RSUs and WAVE-enabled vehicles respectively.

Algorithm 3. Algorithm for Forwarding and Broadcasting of Traffic Information to Respective RSUs and WAVE-enabled Vehicles

```
Input: Vehicles n
 Process:
1. While (GCS received the broadcasted tagged packet from UAV) Do
2. IF (the speed of all vehicles < 120 km/h) // L1 and/or L2
3.          IF (the broadcasted packet is L1 only)
4.                          GCS forward L1 to RSU 2
5.           RSU 2 broadcast L1 to WAVE-enabled vehicles within
its own transmission range
6.             ENDIF
7.       ELSE
8.           IF (the broadcasted packet is L2 only)
9.                     GCS forward L2 to RSU 1
10.           RSU 1 broadcast L2 to WAVE-enabled vehicles within
its own transmission range
11.           ENDIF
12.     ELSE
13. IF (the broadcasted packets are L1 and L2)
14.        GCS forward L1 to RSU 2 and L2 to RSU 1 simultaneously
15.          RSU 2 broadcast L1 and RSU 1 broadcast L2 to WAVE-
enabled vehicles within their own transmission ranges
```

```
            ENDIF
        ENDIF
    ENDWhile
  Output: The traffic information is forwarded and broadcasted to
respective RSUs and WAVE-enabled vehicles
```

3. IMPLEMENTATION AND EVALAUATION

3.1 Prototype Implementation

This section describes the configuration and implementation detail of the different components of the architecture, and discusses their challenges.

3.2 Smart Ground Vehicles Configuration and Implementation

Before implementing the network configuration of smart ground vehicles, we have produced a real mobility model of the vehicles via SUMO simulator. We have assumed that in real highway scenario there are a few number of vehicles present at the same time. And also we have interested to implement and evaluate the integrated architecture in the sparsest network (very less number of vehicles). Thus, as we have shown in Fig 5, we have generated a real mobility model in highway scenario with 30 and 50 vehicles respectively.

In this generation of mobility model, we have used an ordinary (conventional) vehicles/cars those will transform to smart ground vehicles during network configuration. Generally, we have summarized the mobility generation parameters in Table 1. And, before we start the actual network

Figure 5. Sample Mobility Model of Vehicles in Highway Scenario

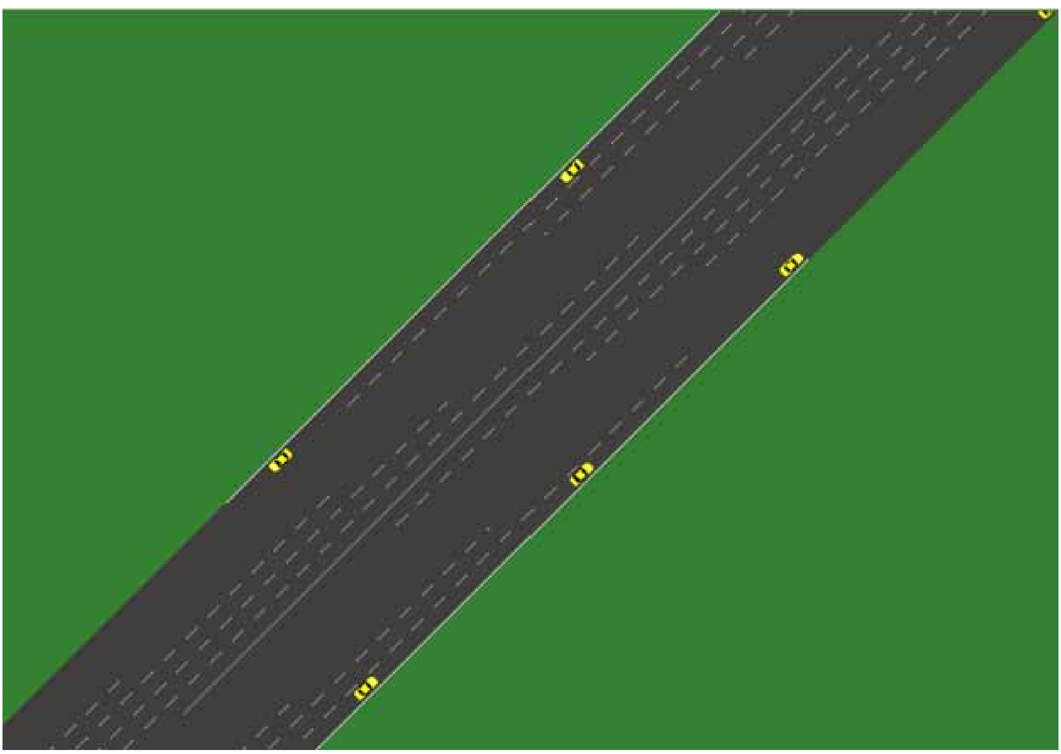


Table 1. Summary of Generation of Mobility Model Parameters

Parameter	Value
Number of Ordinary Vehicles	30 and 50
Type of Street	Highway
Number of Lanes	2 (Different Direction)
Delay between Vehicles	40 milliseconds
Simulation Area (m x m)	100 x 100
Simulation Time	50 Seconds

configuration of vehicles, we have converted the generated trace file of vehicles mobility model to **Tcl** file which is readable via NS-3 network simulator as shown in Fig 6.

After accomplished the generation and conversion of vehicles' realistic mobility model, we have proceeded the network configuration of the vehicles or operation of transformation from ordinary vehicles to smart ground vehicles. As we have demonstrated in Fig 3, the on-board of the smart ground vehicles in communication interface layer have mounted IEEE 802.11p (WAVE), LTE/4G (E-UTRAN) and IEEE 802.11b (on-board drone) interfaces. As an initial step of the configuration, we have directly imported the mobility Tcl file or we have called the full path of the file to use the generated vehicles mobility in NS-3.

3.2.1 WAVE Interface Configuration on Vehicles

We have configured the IEEE 802.11p communication interface on-board the vehicles to acquire a traffic information when the RSUs broadcast it within their own coverage area. To configure the interface, we have primarily used *YansWifiPhyHelper* and *WaveMacHelper* (ns-3, 2020) of NS-3 helpers which are implemented on PHY and MAC layers of vehicles respectively.

By using these NS-3 helpers, we have configured a few basic attributes for vehicles on PHY and MAC layers correspondingly as shown in Table 2. And the attributes are combined and installed in a single communication interface of vehicles via *Wifi80211pHelper*. Then, we have provided IPv4 network address for the interfaces to enable IP communication between vehicles and RSUs (V2I downlink communication).

However, we have only designed and considered a downlink communication, and it has highly depended on the coverage area of the infrastructure instead of the vehicle range. Thus, the WAVE transmission range of vehicles is not significant during actual simulation.

3.2.2 E-UTRAN Interface Configuration on Vehicles

We have configured the LTE/4G communication interface on the vehicles to get a safety information when the eNB broadcast it within its own cell. To configure the E-UTRAN interface, we have used NS-3 *LteSpectrumPhy* that implement on PHY layer and *LteHelper* (ns-3, 2020) which takes care of the configuration of the LTE radio access network, as well as coordinating the setup and release of EPS bearers. Based on the helpers, we have configured some common attributes for vehicles and eNB as demonstrated in Table 3. Furthermore, we have provided IPv4 network address for the interface of vehicles to enable a communication with a remote host via LTE/4G core network (EPC server) such as a communication with UAV's GCS (V2I downlink communication).

3.2.3 IEEE 802.11b Interface Configuration on Vehicles

Here, we have discussed the configuration of the IEEE 802.11b communication interface on vehicles to acquire UAV's beaconed message, and tagged information when the UAV broadcast it within its

Figure 6. Sample Generated Mobility Model of Vehicles in Tcl File

ns2mobility.tcl

```
$node_(0) set X_ 18.78
$node_(0) set Y_ -11.56
$node_(0) set Z_ 0
$ns_ at 2.0 "$node_(0) setdest 18.78 -11.56 60"
$ns_ at 2.1 "$node_(0) setdest 18.79 -11.55 60"
$ns_ at 2.2 "$node_(0) setdest 18.83 -11.51 60"
$ns_ at 2.3 "$node_(0) setdest 18.88 -11.46 60"
$ns_ at 2.4 "$node_(0) setdest 18.95 -11.39 60"
$ns_ at 2.5 "$node_(0) setdest 19.04 -11.3 60"
$ns_ at 2.6 "$node_(0) setdest 19.14 -11.2 60"
$ns_ at 2.7 "$node_(0) setdest 19.26 -11.08 60"
$ns_ at 2.8 "$node_(0) setdest 19.39 -10.95 60"
$ns_ at 2.9 "$node_(0) setdest 19.54 -10.8 60"
$ns_ at 3.0 "$node_(0) setdest 19.7 -10.64 60"
$ns_ at 3.1 "$node_(0) setdest 19.88 -10.46 60"
$ns_ at 3.2 "$node_(0) setdest 20.07 -10.27 60"
$ns_ at 3.3 "$node_(0) setdest 20.28 -10.06 60"
$ns_ at 3.4 "$node_(0) setdest 20.49 -9.85 60"
$ns_ at 3.5 "$node_(0) setdest 20.73 -9.61 60"
$ns_ at 3.6 "$node_(0) setdest 20.98 -9.36 60"
$ns_ at 3.7 "$node_(0) setdest 21.24 -9.1 60"
$ns_ at 3.8 "$node_(0) setdest 21.52 -8.82 60"
$ns_ at 3.9 "$node_(0) setdest 21.81 -8.53 60"
$ns_ at 4.0 "$node_(0) setdest 22.11 -8.23 60"
$ns_ at 4.1 "$node_(0) setdest 22.44 -7.9 60"
$ns_ at 4.2 "$node_(0) setdest 22.77 -7.57 60"
$ns_ at 4.3 "$node_(0) setdest 23.12 -7.22 60"
$ns_ at 4.4 "$node_(0) setdest 23.49 -6.85 60"
$ns_ at 4.5 "$node_(0) setdest 23.86 -6.48 60"
$ns_ at 4.6 "$node_(0) setdest 24.25 -6.09 60"
$node_(1) set X_ 18.78
$node_(1) set Y_ -11.56
```

own coverage area. To configure the interface, we have used *YansWifiPhyHelper* and *WifiMacHelper* (ns-3, 2020) of NS-3 helpers which employed on PHY and MAC layers of vehicles respectively. By using the helpers, we have configured some basic attributes for vehicles on PHY and MAC layers correspondingly as shown in Table 4. And the attributes have combined and installed in a single communication interface of vehicles via *WifiHelper*.

Then we have provided IPv4 network address for the interface of vehicles to enable IP communication between vehicles and UAV (V2I downlink communication). Besides, the IEEE 802.11b transmission range of vehicles are not worth during actual simulation due to V2I downlink communication.

Table 2. Attributes of WAVE Interface on Vehicles

Attribute	Value
Network Address	10.1.2.0/24
Transmission Radio Range	250 to 300m
Channel Width	10MHz
Number of Transceiver Antenna	1
Propagation Delay	Constant Speed Propagation Delay Mode (ns-3, 2020)
Energy Detection Threshold	Default
Rx Noise Figure	Default (1dB)

Table 3. Attributes of E-UTRAN Interface on Vehicles

Attribute	Value
Network Address	7.0.0.0/8
Control Error Model	true (ON)
Data Error Model	true (ON)
RRC	true (ON)
PDSCH CQI generation	true (ON)
AMC Model	Default (PiroEW2010)

3.2.4 Long Term Evolution Configuration and Implementation

In this Section, we have described the LTE/4G wireless access infrastructure configuration and implementation regards to the integrated architecture. Actually, in this configuration, we have used two kinds of models, *LTE* and *EPC model* respectively.

In the *LTE model*, we have configured the eNodeB with its RRC at PHY layer by using NS-3 *LteHelper*. While in the *EPC model*, we have used NS-3 *EpcHelper* (ns-3, 2020) which takes care of the configuration of the EPC server, to use as a gateway when the GCS broadcast a safety information to LTE-enabled vehicles. Furthermore, we have used NS-3 *PointToPointHelper* which is used to make a point-to-point wired link between EPC server and UAV's GCS. And finally, we have provided a

Table 4. Attributes of IEEE 802.11b Interface on Vehicles

Attribute	Value
Network Address	10.1.4.0/24
Transmission Radio Range	150 to 200m
Number of Transceiver Antenna	1
Propagation Delay	Constant Speed Propagation Delay Model (ns-3, 2020)
Energy Detection Threshold	default
Rx Noise Figure	default (1dB)

Table 5. Attributes of LTE/4G Configuration

Attribute	Value
Network Address (P2P)	10.1.1.0/24
Data Rate (P2P)	500kbps
Delay (P2P)	2 milliseconds
Control Error Model	true (ON)
Data Error Model	true (ON)
RRC	true (ON)
PDSCH CQI generation	true (ON)
AMC Model	default (PiroEW2010)
DlEarfcn (for eNB)	default (100)
UlEarfcn (for eNB)	default (18100)

network address for the point-to-point interfaces between EPC server (GW) and GCS to enable a wired IP communication. In Table 5, we have summarized the major attributes of the LTE/4G configuration.

Figure 7 shows the broadcasting of safety information to all LTE-enabled vehicles using LTE/4G network when UAV's GCS forwarded the information via EPC server (GW). Actually, we have used *NetAnim* for visualization, and the dots where on the lines indicates the movement of the vehicles on their respective lanes, as well as each circle represents the capacity of the eNB cell.

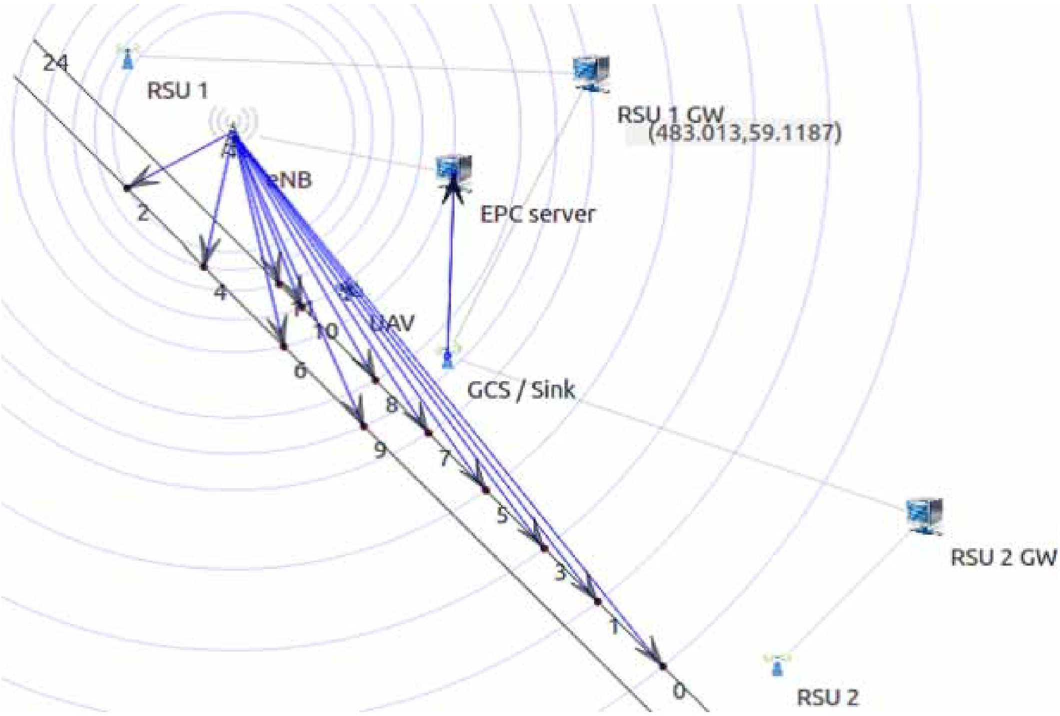
3.2.5 Road Side Units Configuration and Implementation

Here, we have presented the configuration of RSU 1 & RSU 2 wireless access infrastructures. The RSUs configurations are similar with WAVE interface on vehicles configuration. However, the RSUs have their own gateways which are used to make communications with UAV's GCS. Moreover, we have provided three network addresses which one for the WAVE interfaces of RSUs (*10.1.3.0/24*), the second for the point-to-point interfaces between RSU 1 and its GW (*10.1.8.0/24*) and the third for the point-to-point interfaces between RSU 2 and its GW (*10.1.9.0/24*). Figure 1.8 shows the RSU 1 broadcasting a traffic information to WAVE-enabled vehicles those being in RSU 1 coverage area when UAV's GCS forwarded the information via RSU 1 GW. Each circle indicates the capacity of the UAV and RSU 1 coverage area.

3.2.6 UAV's Ground Control Station (GCS) Configuration and Implementation

In this configuration, there are some similarities with the configuration of IEEE 802.11b interface on vehicles such as regards to a number of transceiver antenna, energy detection threshold, and transmission range. However, we have used NS-3 *PointToPointHelper* which used to create point-to-point wired links between UAV'S GCS and EPC server, UAV's GCS and RSU 1 GW, and UAV's GCS and RSU 2 GW correspondingly. Furthermore, the GCS has also three IP address for its respective point-to-point interfaces. And again, it has another IP address for its own IEEE 802.11b interface that used to make IP-enabled downlink communication with UAV via LOS. Figure 9 shows the UAV'S GCS forwarding a traffic information to RSU 1 via RSU 1 GW. The circles indicate the capacity of the UAV coverage area, as well as the arrows, represents UAV broadcasted the tagged info within its own transmission range and then GCS forwarded it to RSU 1.

Figure 7. Sample Broadcasting of Safety Information via LTE/4G Network



3.2.7 Unmanned Aerial Vehicle (UAV) Configuration and Implementation

In this Section, we have presented the network configuration and implementation of Unmanned Aerial Vehicle (Drone) as much as possible. As mentioned in the work (Estifanos, 2018), the UAV has about 10m height from the ground and a hovering motion. Based on these circumstances, we have configured some network parameters of UAV as almost similar as its GCS as shown in Table 6.

Figure 10 shows the UAV sensing (tagging) and broadcasting operations within its own coverage area to on-board drone vehicles and its GCS via LOS. Actually, for sensing operation we have used ***GetPosition()***, ***GetVelocity()***, ***GetReferenceCount()*** and ***GetId()*** functions of sensors to detect the current position, speed, total number and ID of smart ground vehicles respectively. For tagging operation, we have adopted a tag header file of NS-3 (ns-3, 2020), it is called "***steve.h***". Additionally, for broadcasting the tagged information, we have used ***socket Send()*** function.

3.2.8 The Integrated Architecture Implementation and Challenges

Generally, the integrated architecture has some major components and communications that presented in Table 7.

We have tackled by some challenges of the different components of architecture during their configuration and implementation phase. The primary challenge is the integrating of the three various protocols (standards), IEEE 802.11b, LTE/4G and IEEE 802.11p (DSRC/WAVE). Though we have settled it by makings a different point-to-point wired communications via their different gateways (Internet).

While the other challenge is when LTE/4G network broadcast the safety info to 4G-enabled ground vehicles within its cell, it has spent a mighty processing (simulating) time of NS-3. Hence, due to this fact, the simulation process of safety info broadcasting task via LTE/4G network is very

Figure 8. Sample Broadcasting of Traffic Information via RSU 1

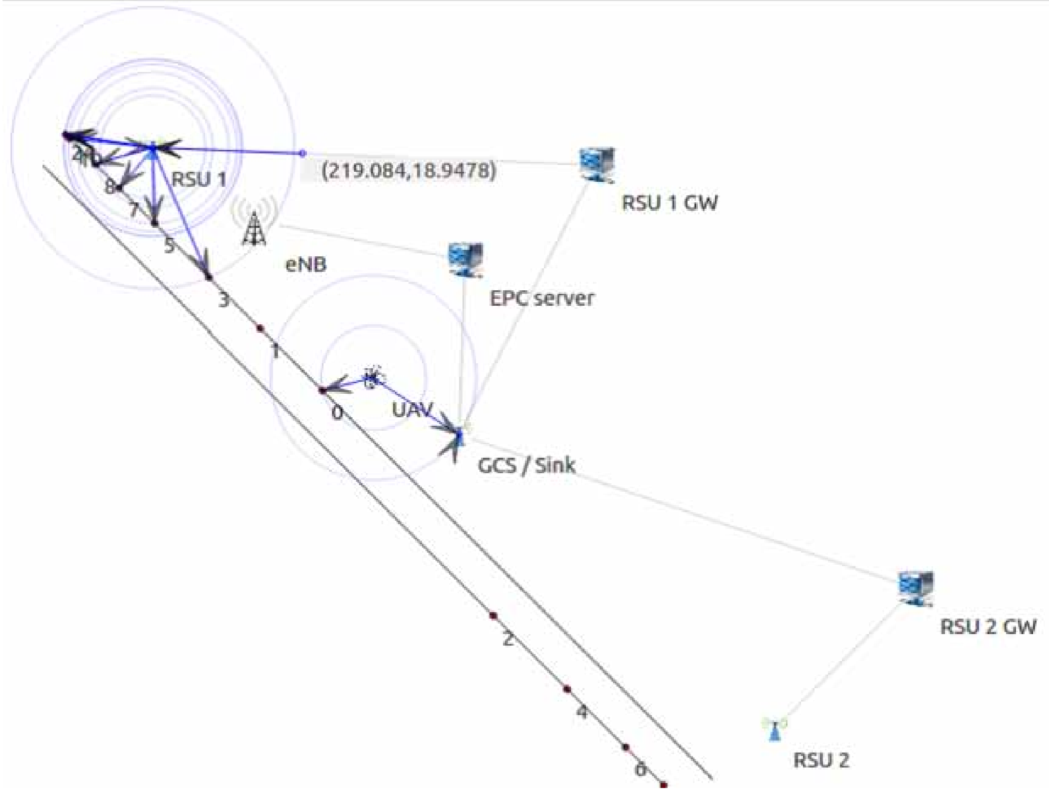


Figure 9. Sample Forwarding of Traffic Info from GCS to RSU 1

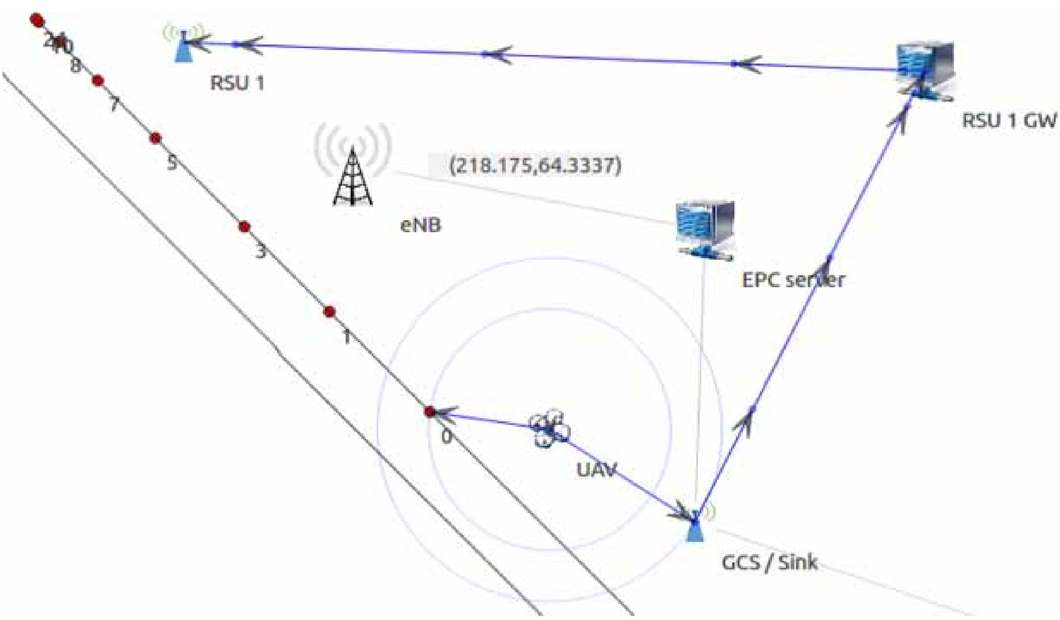


Table 6. Attributes of UAV (Drone) Configuration

Attribute	Value
Network Address	10.1.4.0/24
Transmission Range	150 to 200m
Height	~10m
Mobility	Hovering Motion
Number of Transceiver Antenna	1
Propagation Delay	Constant Speed Propagation Delay Model (ns-3, 2020)
Energy Detection Threshold	default
Rx Noise Figure	default (1dB)

Figure 10. Sample Operations of UAV's Sensing (Tagging) and Broadcasting Vehicles Info

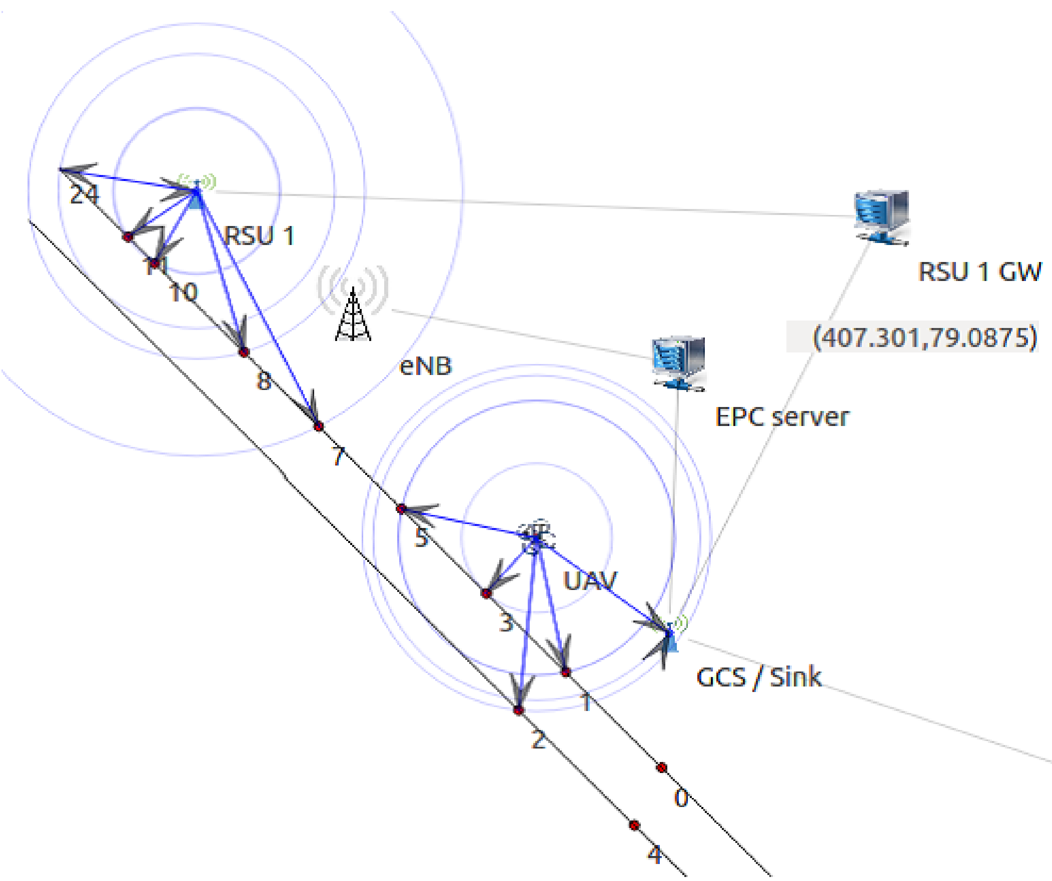


Table 7. Major Components/Communications of Integrated Architecture

S/N	Name of Component/Communication	Total Number
1.	Wireless Access Network Infrastructures (UAV, RSU 1, RSU 2, eNB and GCS)	5
2.	Gateways (*RSU 1 & RSU 2 GWs, EPC server and GCS*)	4
3.	Smart Ground Vehicles	8, 12, 50
4.	Highway	1 with two-lanes
5.	Point-to-Point Wired Communications	6

sluggish. However, it has no relation with the performance of LTE/4G network. Besides, we have tried to overcome this sluggish problem by incrementing the simulation speed of NS-3 during actual simulation period.

3.3 Simulation Experiment and Results

We have generated the Tcl file of vehicles real mobility model via SUMO simulator. Then, we have exported the Tcl file to NS-3 simulator to implement the network configurations of the integrated architecture with respects to the mobility model. The simulation period takes *50 seconds* due to high speed of vehicles in highway scenario, as well as the simulation area is *740m x 560m*. The different parameters are shown in Table 8.

Figure 11. The Integrated Novel Architecture in NetAnim Visualizer

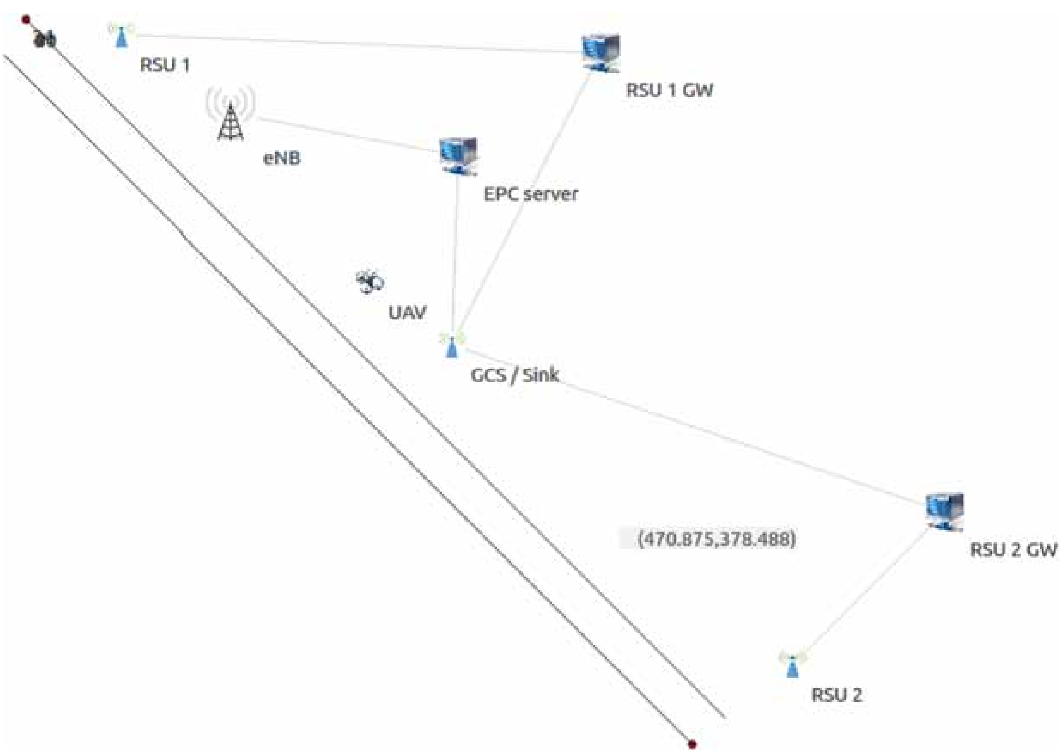


Table 8. Summary of Simulation Parameters

Parameter	Value
Number of Smart Ground Vehicles	8,12 and 50
Type of Street	Highway
Number of Lanes	2 with different direction
Transmission Range of UAV	150 to 200m
Transmission Range of RSU 1 & RSU 2	250 to 300m
Data Rate	500kbps
Scenario Size (m x m)	740 x 560
Simulation Time	50 seconds

3.3.1 Performance Evaluation Metrics and Results

In this section, in order to optimize the performance of VANET communications and satisfy the requirements of its basic applications (safety and traffic) via the integrated novel architecture with its forwarding schemes, we have evaluated the performance of the designed solution with existing work (basic principle of VANET communications in highway scenario that we have implemented as it has direct V2V and V2I communications/hybrid architecture (Issac & Latiff, 2014), (Vehicular Communication System, 2020), (Fan & Yu, 2007), (Saheb et al., 2006)). The designed solution is evaluated in terms of packet delivery ratio, mean (average) delay and total throughput. According to (ns-3, 2020), the metrics are discussed as follows:

1. **Packet Delivery Ratio (PDR):** It is the ratio of a total number of delivered data packets to the total number of data packets transmitted by all sources. This evaluation metric will give us a concept of how well the designed solution is performing in terms of packet delivery at different network (vehicle) density.
2. **Mean Delay (MD):** It is the average time delay for data packets received. This metric is calculated by dividing the sum of all end-to-end delays for all received packets by total received packets. This might include the processing delay at intermediate nodes (GWs).
3. **Throughput (T):** It is the total number of delivered data packets divided by the total duration of simulation time. In this case, the throughput of each of the forwarding and broadcasting schemes in terms of a number of information delivered per one second is evaluated. Additionally, the throughput is measured in Mbps.

Based on the evaluation metrics, the performance of the integrated novel architecture with its forwarding schemes is evaluated using NS-3 with its flows monitor.

After realizing extensive simulations with varied vehicle sizes regarding to highway scenario for the defined parameters, vector, and scalar data are recorded and stored in a PCAP and spreadsheet files. The data can later be analyzed and transformed into a table as shown in Table 9, as well as demonstrated in a graph as follows.

To evaluate the ability of the integrated architecture to reliable delivery of packets, we have computed and compared the PDR achieved by a testing packet. In Table 9, we have shown the total number of packets sent and delivered to the destinations on the forwarding and broadcasting schemes.

Packet delivery ratio for the integrated architecture (broadcasting and forwarding safety and/or traffic information schemes) and existing work in highway scenario increases as the size of the smart ground vehicles (network) increases. This is because, at higher vehicles size, when the wireless access

Table 9. Performance Evaluation Results

	Network Size (#Vehicle)	Total Packet Sent (#Packet)	Total Packet Delivered (#Packet)	Performance		
				PDR (%)	MD (Second)	T (Mbps)
Existing Work	8	1096	434	39	0.0683754	2.14379
	12	1939	777	40	0.0435663	2.49405
	50	8079	3237	65	0.0232323	5.96332
Integrated Novel Architecture	8	2297	1266	55	0.0197291	8.96427
	12	2086	1388	66	0.0193086	10.3705
	50	8691	5783	95	0.0156598	15.6532

network infrastructures broadcast a packets/information, there is a high possibility that the presence of the vehicle in the infrastructures transmission range.

In order to this, the packets/information will be received by many vehicles. As shown in Figure 12, compared with existing work in highway scenario, the proposed integrated novel architecture has the highest packet delivered ratio because we have used high capable wireless access infrastructures like LTE/4G and UAV System with a good forwarding and broadcasting schemes as we have not implemented a V2V communication directly, however, we tried to improve it through integrated infrastructures (V2I downlink communications). Moreover, the results revealed that the integrated architecture with its forwarding schemes has capable to minimize the intermittent connectivity (high packet loss) of a direct V2V communication.

Figure 12. PDR Results for Integrated Architecture and Existing Work in Highway Scenario

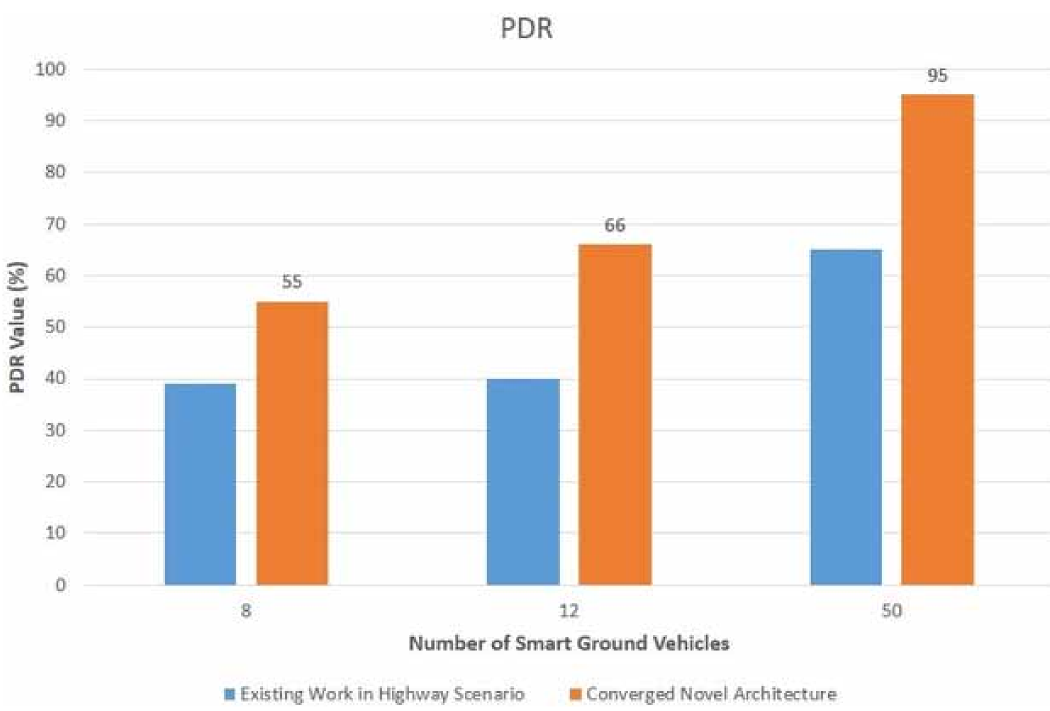
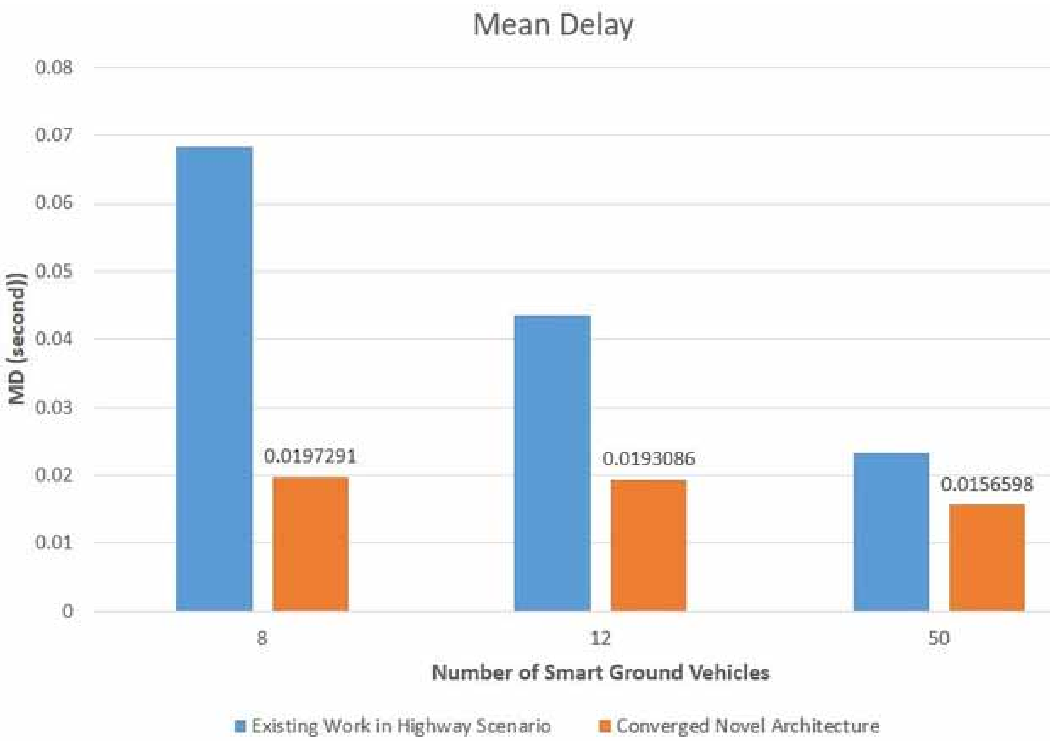


Figure 13. MD Results for Integrated Architecture and Existing Work in Highway Scenario

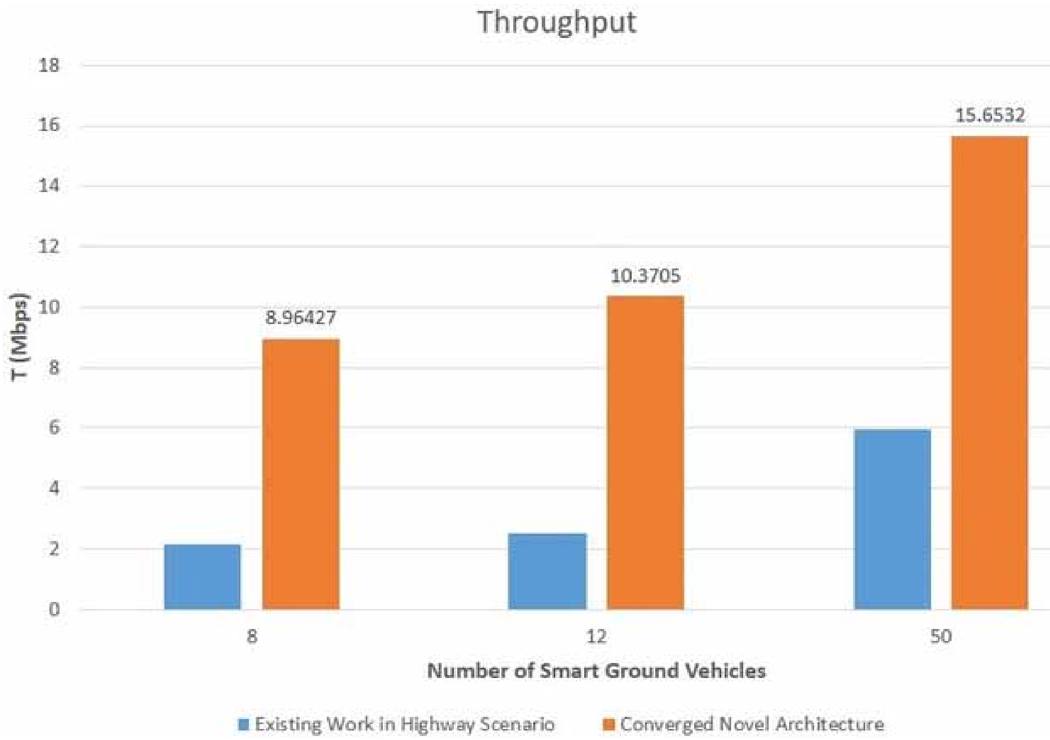


As we observe from the simulation results shown in Figure 13, the mean delay for both works decreases as the size of the smart ground vehicles (network) increases. This is due to the fact that if the number of vehicles increases within the transmission ranges of wireless access network infrastructures then the total number of received packets or PDR increases as we have mentioned in Figure 12. In other words, if the total number of packets/information delivered increases within the coverage areas of the infrastructures, the mean delay will dramatically fall because we have calculated mean delay as the sum of all end-to-end delays for all received packets divided by the total delivered packets. Furthermore, as can be seen from the graph, the proposed integrated architecture has revealed lower mean delay in all vehicles size than the existing work in highway scenario. This is because the architecture has used integrated infrastructures with optimized forwarding schemes those are capable to enhance the PDR and consequently the mean delay minimized. Furthermore, the results have revealed that the integrated architecture with its forwarding schemes has capable to achieve the requirement of delay-sensitive or high data rate required VANET applications (safety).

As can be seen from the Figure 14, the total number of packets/information which is effectively delivered by all destination smart ground vehicles within a simulation time increases in the network which is more efficient. This efficiency comes through well-optimized forwarding and broadcasting schemes via integrated infrastructures. As well as, the total throughput increases when the number of smart ground vehicles increases, this is because, if the number of smart ground vehicles increases within transmission range of infrastructures, the total number of delivered bytes/packets/information will increase as we have discussed in Figure 12.

Furthermore, from Figure 14, it can be observed that the performance of the proposed integrated novel architecture provided better packet/information delivery over the simulation time. This is due to the fact that applying the optimized forwarding schemes on the integrated architecture helps

Figure 14. T Results for Integrated Architecture and Existing Work in Highway Scenario



forwarding the information (safety/traffic) to appropriate destinations via right infrastructure. As a results, the forwarding schemes through the integrated architecture is very effective in delivering the safety/traffic information to appropriate smart ground vehicles within the specified simulation time. In other words, the results revealed that the integrated architecture with its forwarding schemes has proficient to achieve specifically the demand of delay-sensitive or high data rate required VANET applications (safety), and also it could have minimized that the bandwidth usage of periodically broadcast a beacon or Hello message by vehicles in existing work, because we have replaced it by UAV's operations and V2I downlink communications. Additionally, a higher value of total throughput requires higher packet delivery ratio and lower mean delay.

4. CONCLUSION

The simulation experiment results show that the proposed integrated novel architecture provides a better performance for VANET communications and some basic applications in highway scenario with high throughput and packet delivery ratio, and minimizing delay. This is due to the fact that in the proposed integrated novel architecture, we was designed and implemented an optimized forwarding scheme regards to the right infrastructures. As we see the results, all the architecture evaluation metrics have worth performance which makes the proposed integrated novel architecture a nominee and foremost choice architecture for implementing (deploying) VANETs in highway scenario.

5. RECOMMENDATION

Though we did my best to realize the proposed integrated novel architecture with its forwarding schemes for VANET communications in highway scenario with the objective of overcoming the limitations of existing work (the basic principle of VANET communications in highway scenario), we do not trust that the architecture is standard enough to incorporate potential matters in VANETs highway scenario. For example, despite the importance of the issue, we have not considered the security and privacy aspect of the VANETs in my architecture since it was beyond the scope of this work. Thus, we hope that the proposed integrated architecture can be enriched in such a way that the security of VANETs is taken into account.

Regarding forwarding schemes, we have not considered/implemented a geo-cast forwarding scheme for RSUs to overcome the bandwidth consumption when the RSUs (RSU 1 and RSU 2) broadcasts the traffic information to WAVE-enabled vehicles within their own coverage areas (both lanes). For better clarification, by using geo-cast forwarding scheme, RSU 1 forwards a traffic information (L2) to lower lane only within its own transmission range, and as well as RSU 2 forwards a traffic information (L1) to upper lane only within its own transmission range. Therefore, we believe that the proposed integrated novel architecture with its forwarding schemes can be enriched in such a way that the geo-cast forwarding scheme on RSUs is taken into account.

Regarding infrastructure deployment consideration, we have not considered an optimal deployment of many UAVs (Drones) to proceed UAV's operations (sensing, tagging, and broadcasting of the current states of on-board drone vehicles information within UAV coverage area) on different areas of highway. Hence, we hope that the proposed integrated novel architecture can be enriched in such a way that the optimal deployment of many drones on different areas of highway is taken into account.

Furthermore, concerning with scenarios, we have not considered the implementation of my integrated architecture in urban scenario. Thus, we trust that the proposed integrated novel architecture can be enriched in such a way that the implementing/deploying the proposed architecture in urban scenario is taken into account.

ACKNOWLEDGMENT

This work would not have been possible without the endless support of son of St. Merry, Almighty God, thus we praise always the name of him and his mother.

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